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Remote sensing study on the Pisa plain

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Multispectral images with medium-high resolution were acquired from the SPOT, ALOS AVNIR-2 and TERRA ASTER satellites in order to detect morphological evidence of buried palaeochannels and wetlands in the Pisa plain. Different types of image elaboration techniques were attempted and cross-compared, such as the application of different false colour composites, image enhancement techniques and image transformation. Results demonstrate a good correspondence of detected features with those previously highlighted in the framework of the MAPPA Project through different geomorphological analysis techniques.

Keywords: Satellite images, palaeochannels, wetlands, Pisa

1. Satellite data

Several multispectral images were acquired with the aim to integrate the geomorphological knowledge of the Pisa plain resulting from the previous project phases, and to evaluate the potential of satellite remote sensed data.

In particular, this kind of approach focused on palaeochannel reconstruction and on complementing the stereoscopic analysis carried out using aerial photographs from 1943 to 2010 (Bini *et alii,* 2011).

Despite the fact that very high resolution satellite data (e.g. Geoeye-1, 2 m pixel resolution), were available for the study area, the average dimension of the features to be investigated was too large compared to the resolution of the VHR images. Consequently, high noise levels were expected with probably very low accuracy.

For this reason we selected remote sensing data with medium-high resolution (pixel=10 m) from the SPOT, ALOS AVNIR-2 and TERRA ASTER satellites.

The SPOT platform (*Système Pour l'Observation de la Terre*) is a French (CNES) Earth-imaging programme.

SPOT 5 is the most recent high-resolution optical satellite, which was launched in 2002 and is still operational.

SPOT 5 has two high resolution geometrical (HRG) instruments that offer a higher resolution of 2.5 to 5 metres in panchromatic mode and 10 metres in multispectral mode. The SPOT imaging swath covers a wide area (60 x 60 km) and together with the high resolution provides a good compromise for applications such as medium-scale mapping (at 1:25 000 and 1:10 000 locally).

The multispectral image selected from the SPOT Image catalogue, considering seasonality and cloud-free coverage, was acquired on 3 March 2006. It is characterised by four spectral bands from the visible (VIS) through the near-infrared (NIR) and short-wave infrared (SWIR) regions of the electromagnetic spectrum. The green, red and NIR bands have a 10 m spatial resolution while the SWIR band has a 20 m spatial resolution (usually resampled by SPOT image corporation to 10 m prior to delivery). The spectral and acquisition characteristics of the image are given in Table 1.

The second type of multispectral remote sensing data collected was acquired from the ALOS satellite that belongs to the Japanese Earth observing satellite programme.

Spectral bands	Spatial resolution (m)	Spectral range (µm)
B1: green	10	0.50 – 0.59
B2: red	10	0.61 – 0.68
B3: near infrared	10	0.78 – 0.89
B4: short wave infrared (SWIR)	20	1.58 – 1.75

Table 1. SPOT 5 sensor characteristics.

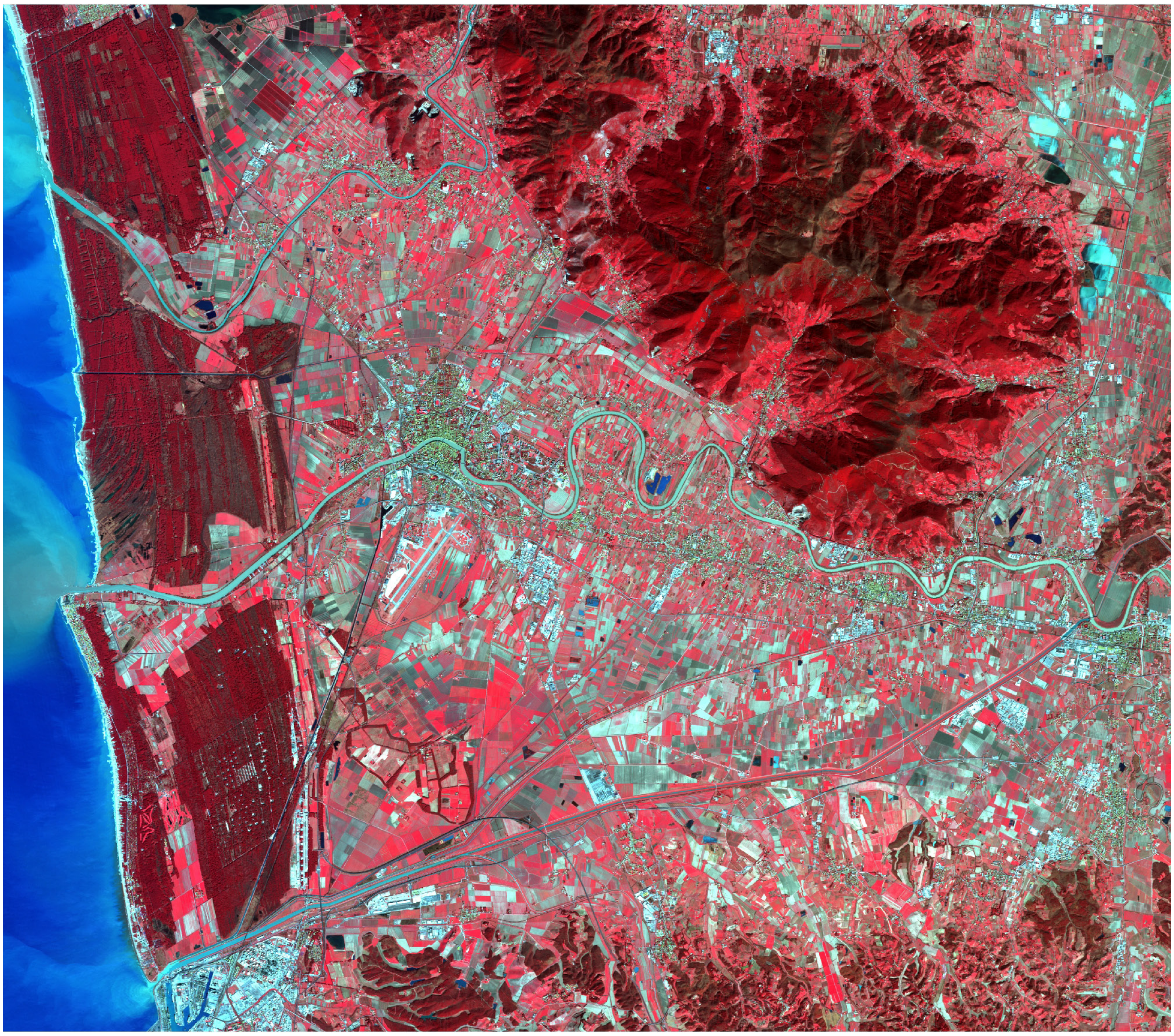

Figure 1. SPOT 5 acquired image over the study area represented in false colour composite 321 RGB.

ALOS (Advanced Land Observing Satellite) was launched in January 2006 and carried three different sensors. AVNIR-2 was a multispectral sensor with four spectral bands in the visible and near-infrared region of the electromagnetic spectrum. Its spatial resolution was 10 metres and swath width was 70 km. The purpose of the sensor was to acquire data for precise land coverage observation. The other two sensors in ALOS were: PRISM, a panchromatic radiometer (0.52-0.77 µm) with high resolution (2.5 m), designed to obtain terrain data including elevation, and PALSAR, provided with an active microwave sensor using L-band at a frequency of 1.3 GHz. This satellite is no longer operational. It suffered a power anomaly on 22 April 2011. JAXA (Japanese Aerospace Exploration Agency) stopped the onboard transmitter of the satellite on 12 May 2011.

The best image available was selected from the online catalogue, considering quality, season and cloud-free parameters. The image of 13 July 2007 was acquired.

The characteristics of the AVNIR-2 sensor and the spectral range of the collected image (Fig. 2) are summarized in the table below.

The third set of remote sensing data used for this study was acquired from the TERRA platform and the ASTER sensor.

Due to the very low cost of these images, we were able to acquire two scenes which covered different seasons influencing vegetation growth, with the aim to increase the probability of feature detection.

The Advanced Thermal Emission and Reflection Radiometer (ASTER) can be considered the successor to the widely known Landsat ETM. It was launched by NASA JPL in 1999 and collects data in 14 bands with three subsystems operating in a different spectral region (VNIR, SWIR and TIR) (Fig. 3). It has a mixture of spatial resolutions, ranging from 15 m in the VNIR

ANVIR-2 Characteristics	
Number of bands	4
Wavelenghth	Band 1: 0.42-0.50 μm Band 2: 0.52-0.60 μm Band 3: 0.61-0.69 μm Band 4: 0.76-0.89 μm
Spatial resolution	10 m (at Nadir)
Swath width	700 km (at Nadir)
S/N	>200
MTF	Band 1-3: > 0.25 Band 4: > 0.20
Number of detectors	7000 / band
Pointing angle	-44 to +44 deg
Bit length	8 bits

Table 2. AVNIR-2 sensor characteristics.

Figure 2. Preview of ALOS AVNIR-2 scene acquired on 13 July 2007.

(visible near infrared), to 30 m in the SWIR (shortwave infrared) and 90 m in the TIR (thermal infrared) (Tab. 3). As the SPOT sensor, ASTER does not acquire in the blue spectral range.

The ASTER images used in this study are level 1A data acquired on 1 May 2005 and on 16 February 2007 (Fig. 4). Although the satellite is currently operational, a time acquisition before May 2007 was chosen due to the anomalous saturation of values and striping in SWIR bands which occurred after that period.

Subsystem	Band No.	Spectral range (μm)	Spatial resolution (m)	Quantization levels
VNIR	1	0.52-0.60	15	8 bits
	2	0.63-0.69		
	3N	0.78-0.86		
	3B	0.78-0.86		
SWIR	4	1.60-1.70	30	8 bits
	5	2.145-2.185		
	6	2.185-2.225		
	7	2.235-2.285		
	8	2.295-2.365		
	9	2.360-2.430		
TIR	10	8.125-8.475	90	12 bits
	11	8.475-8.825		
	12	8.925-9.275		
	13	10.25-10.95		
	14	10.95-11.65		

Table 3. Characteristics of the 3 ASTER Sensor Systems (from ASTER Users Handbook).

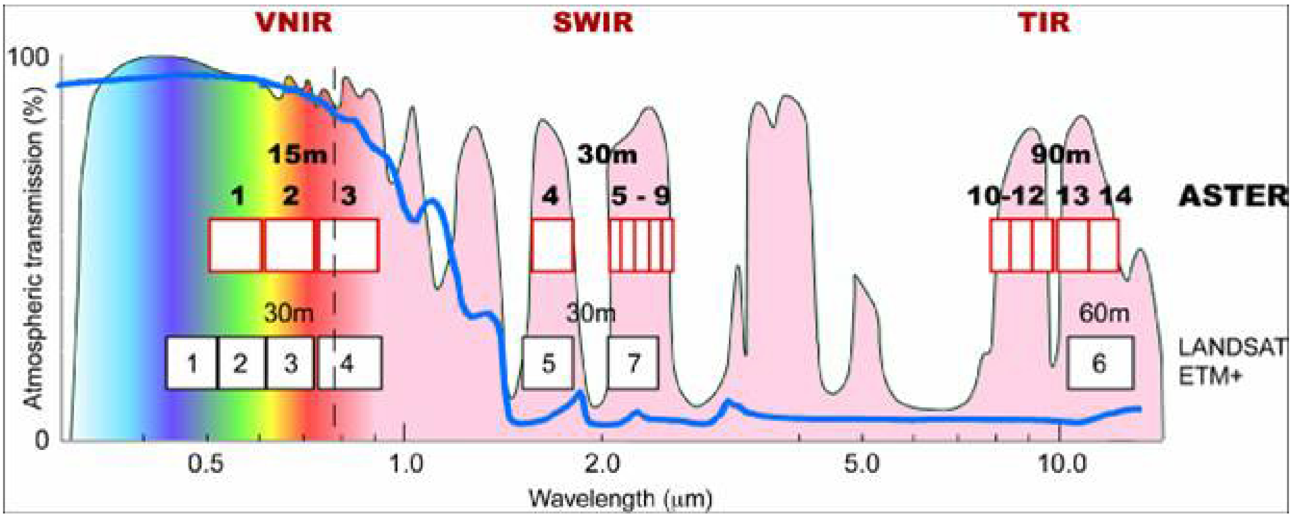

Figure 3. Distribution of ASTER and Landsat bands superimposed on model atmosphere (source: NASA <http://asterweb.jpl.nasa.gov/images/spectrum.jpg>).

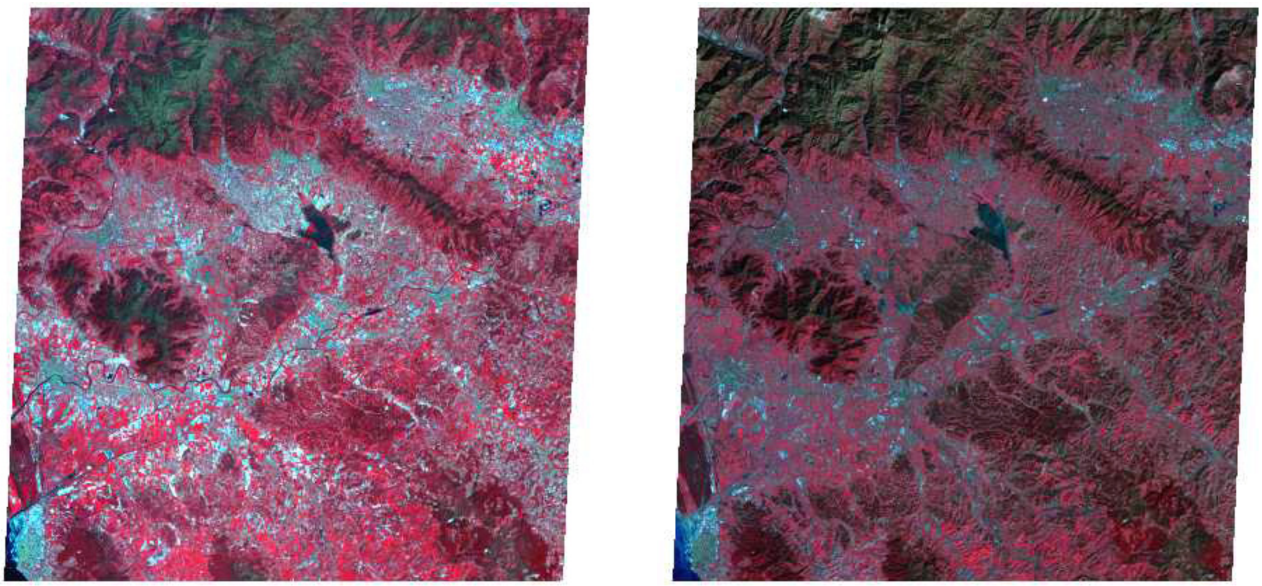

Figure 4. On the left, the May 2005 ASTER image of the Pisa plain and the eastern part of Tuscany; on the right, the February 2007 Aster image (both false colour composite 321 RGB) of the same area. The coverage of both scenes is 60 x 60 km.

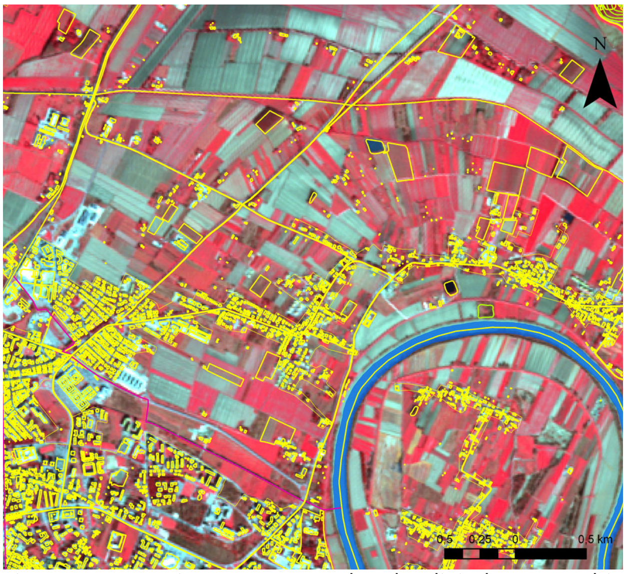

Figure 5. SPOT 5 image compared to the digital topographic map (C.T.R., 10:000) presented with yellow lines.

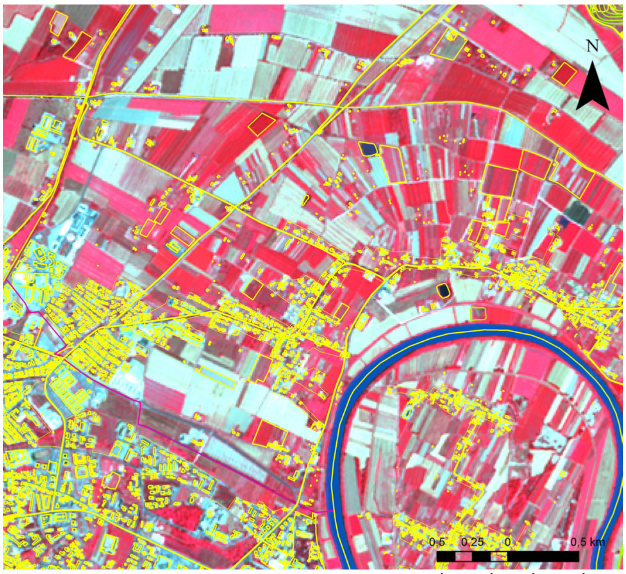

Figure 6. ALOS AVNIR-2 image compared to the digital topographic map (C.T.R., 10:000) presented with yellow lines.

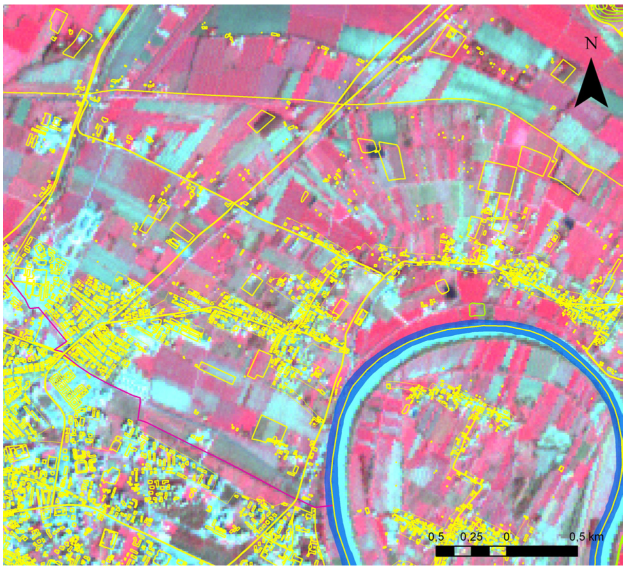

Figure 7. ASTER image (February 2007) compared to the digital topographic map (C.T.R., 10:000) presented with yellow lines. The spatial error positioning is clearly visible.

2. Image elaboration

The whole imagery dataset was checked before the elaboration phase due to the need for pre-processing steps. Only the ASTER dataset needed to be geometrically corrected with a procedure requiring the building of geometry files.

All the images were originally acquired in geographical WGS 84 coordinates and delivered in UTM projection, Zone 32 North. Since the MAPPA project specifications require the Italian Gauss Boaga national coordinate system, all datasets were re-projected into the latter.

In the preliminary checking phase in GIS environment, all the datasets were compared to the most accurate large-scale (1:10:000) digital topographic mapping available (the so-called C.R.T., Regione Toscana) (Fig. 5, Fig. 6 and Fig. 7).

The ASTER images showed a spatial positional error which was not present in the SPOT and ALOS images. This error was fixed using ground control point registration.

According to the MAPPA project objectives, which seek to detect paleochannel features in the Arno alluvial plain, several different types of image elaboration techniques were attempted and cross-compared.

This phase comprised the application of different false colour composites, image enhancement techniques and image transformation.

The best results were selected for the photointerpretation of paleochannel features and wetlands.

For the SPOT 5 acquisition carried out on 6 March 2006, the following elaborations were believed to provide more information about the target features: the 321 RGB colour composite, the first PCA (Principal Component Analysis) component and the SWIR enhanced band.

Figures 8 to 13 below contain some examples of the analysis conducted on SPOT data and each caption describes the specific elaboration shown.

Regarding ALOS AVNIR-2 data, since the data were acquired during the summer period (13 July 2007), the dry soils and extended vegetation cover did not emphasise any hidden traces or identify features of interest. The elaborations performed were only able to confirm for the most part what had already been detected with the previous SPOT dataset, except for a few cases in which ALOS alone provided interesting traces. The following elaborations were applied: false colour composite 432 RGB, decorrelation stretching of false colour composite 432 RGB and NIR enhanced single band (see Fig. 14 to Fig. 17).

Finally, the ASTER imagery was acquired during two different seasonal periods: the first during May 2005 and the second during February 2007. Despite this, the two images did not show useful differences for the study.

The elaborations conducted were the same as for other sensor acquisitions. The area covered by the ASTER images was slightly less than the SPOT and

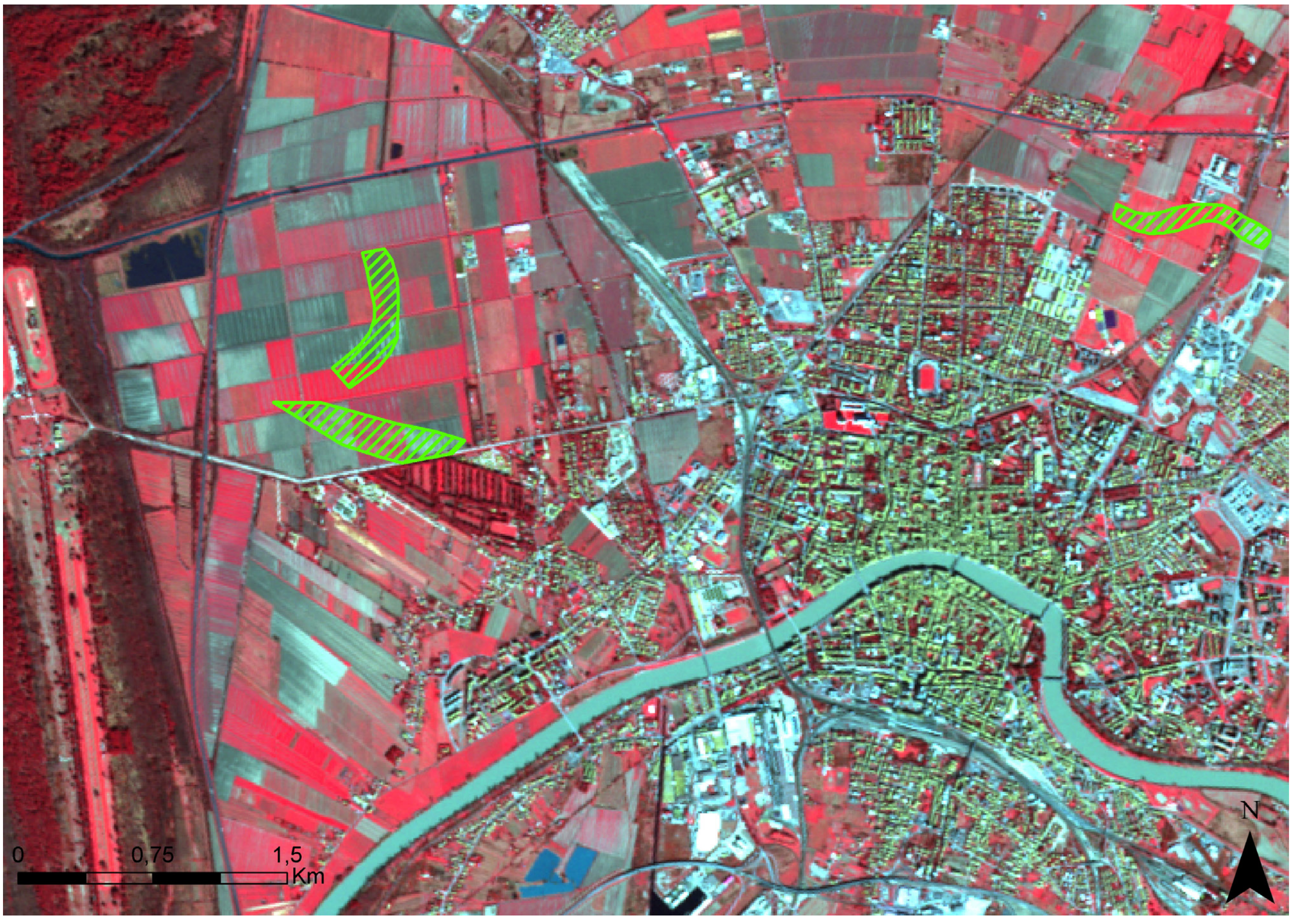

Figure 8. Example of target features highlighted on the 321 RGB false colour composite in the North-West of Pisa. This composite displays the third band (near infrared) in the red channel, the second band (red) in the green channel and the first one (green) in the blue channel. Forest vegetation (in dark red) can be distinguished from grass vegetation in cultivated crops (light red), since vegetation has a high reflectance in the NIR band. The River Arno is shown in light cyan due to the high suspended material content that influences the response in green and red band reflectance. Shallow lakes appear in a darker cyan tone due to the less suspended sediments. Non-vegetated crops appear in light and dark cyan depending on the terrain wetness level (light cyan=dry crop, dark cyan=wet crop). Commercial and industrial buildings around the city of Pisa (in white for the highest response over all bands) may be distinguished from the civil buildings which are shown in a yellowish colour and are related to the different spectral response of red roofs.

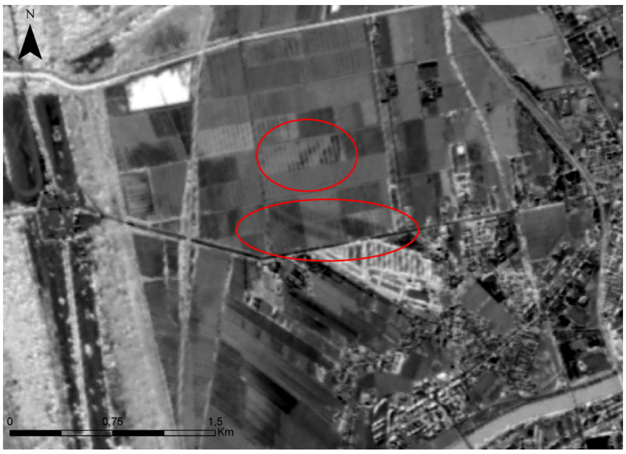

Figure 9. Enlargement of the previous figure. First principal component band. The anomalies on the terrain (identified with red circles) are still visible and more enhanced and noticeable if compared to the surroundings. Principal Component Analysis (PCA) is a multiband transformation technique that compresses data into fewer bands and reduces data redundancy (Richards, 1986). After this decorrelation procedure, the new final multispectral bands contain, in decreasing order, the greatest variance related to unchanged landscape features. In our case, in the figure above, the first Principal Component explains the maximum amount of variation in the 4-dimensional space defined by the four Spot 5 bands.

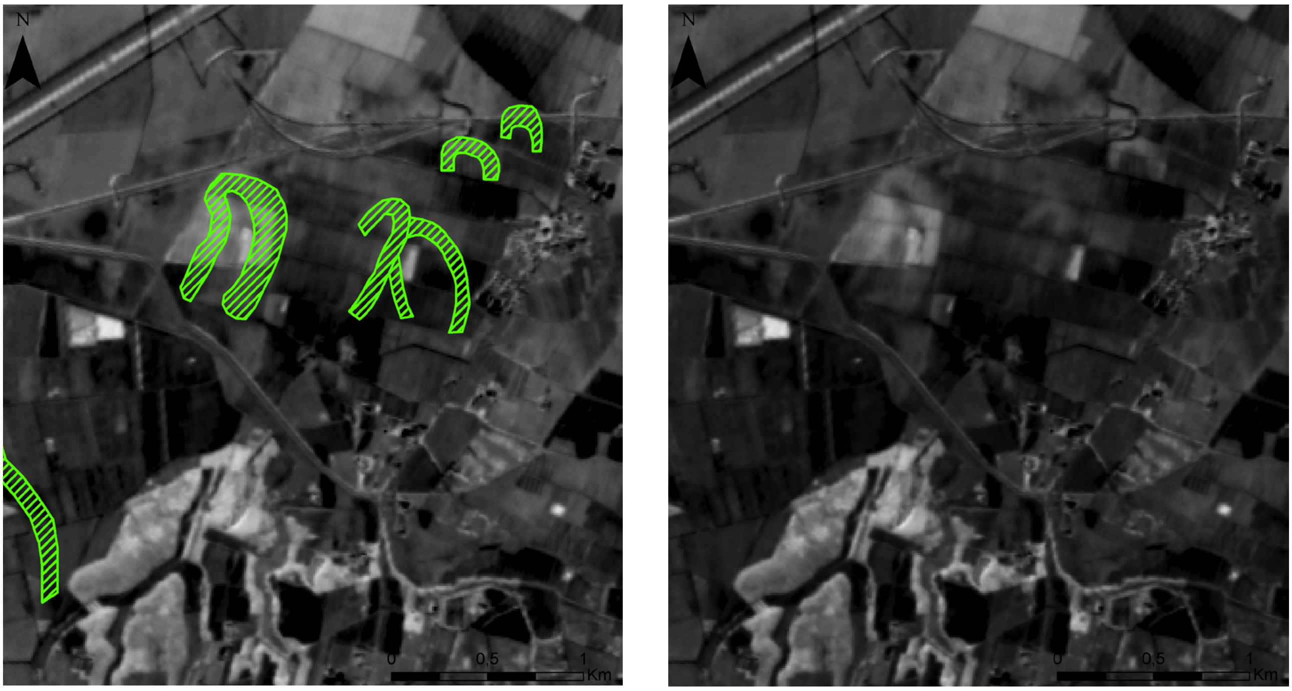

Figure 10 . Another example of anomalous features detected on the first PCA that can be related to paleochannel traces. On the left, the features have been highlighted with green lines, whereas the original image is shown on the right.

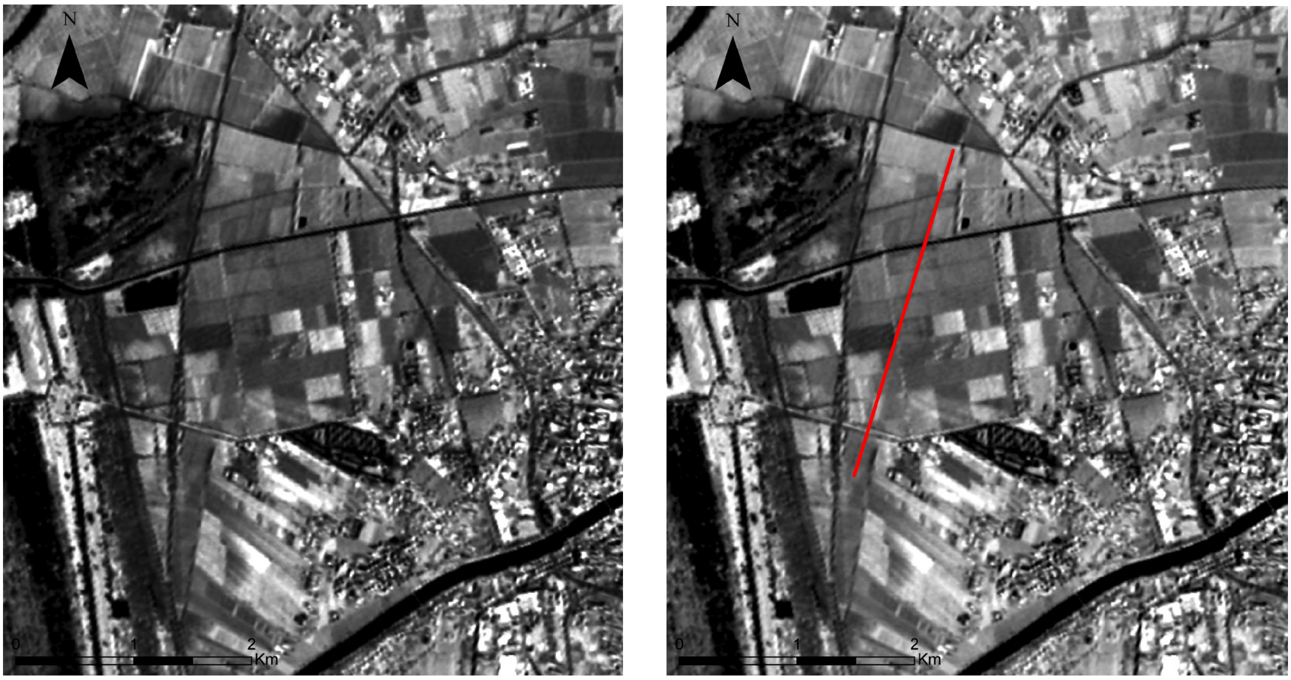

Figure 11. Example of single band enhancement: the SPOT shortwave infrared band. This band, covering the spectral range from 1.58 µm to 1.75 µm, is indicative of vegetation moisture content and soil moisture (see Fig. 13). Contained water absorbs solar radiation, resulting in lower values and darker grey tones. Dry material results in relatively higher values and is represented by lighter grey tones. In the left figure, it is interesting to notice the darker straight line, from north to south, visible to the west of the city before the San Rossore park. The track is highlighted with a red line in the figure on the right. This feature could probably be related to Roman centuriation, but needs to be compared with other information and sources.

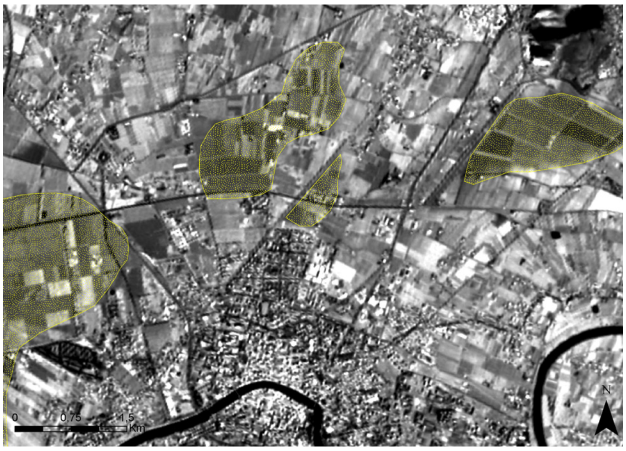

Figure 12. This Spot SWIR band image shows the north area of Pisa. The Spot SWIR band, as mentioned above, is a useful indicator of water content in vegetation and soils (see Fig. 13). We used this relationship to map the wetlands over the study area. The figure above shows a portion of the mapped areas (yellow polygons).

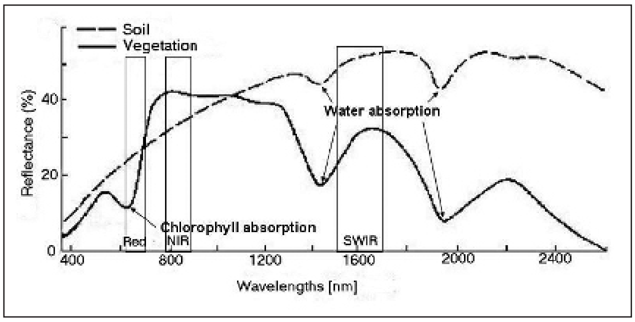

Figure 13. Spectral signature of soil and vegetation and Landsat wavelength bands (Red, NIR, SWIR). The SPOT SWIR band has the same spectral range (1,58-1,75 μm) of Landsat first SWIR band. The peaks of water absorption at 1.45 μm and at 1.95 μm, before and after the SPOT SWIR spectral range, are highlighted (Lillesand and Kiefer, 1994; Altobelli *et alii,* 2010).

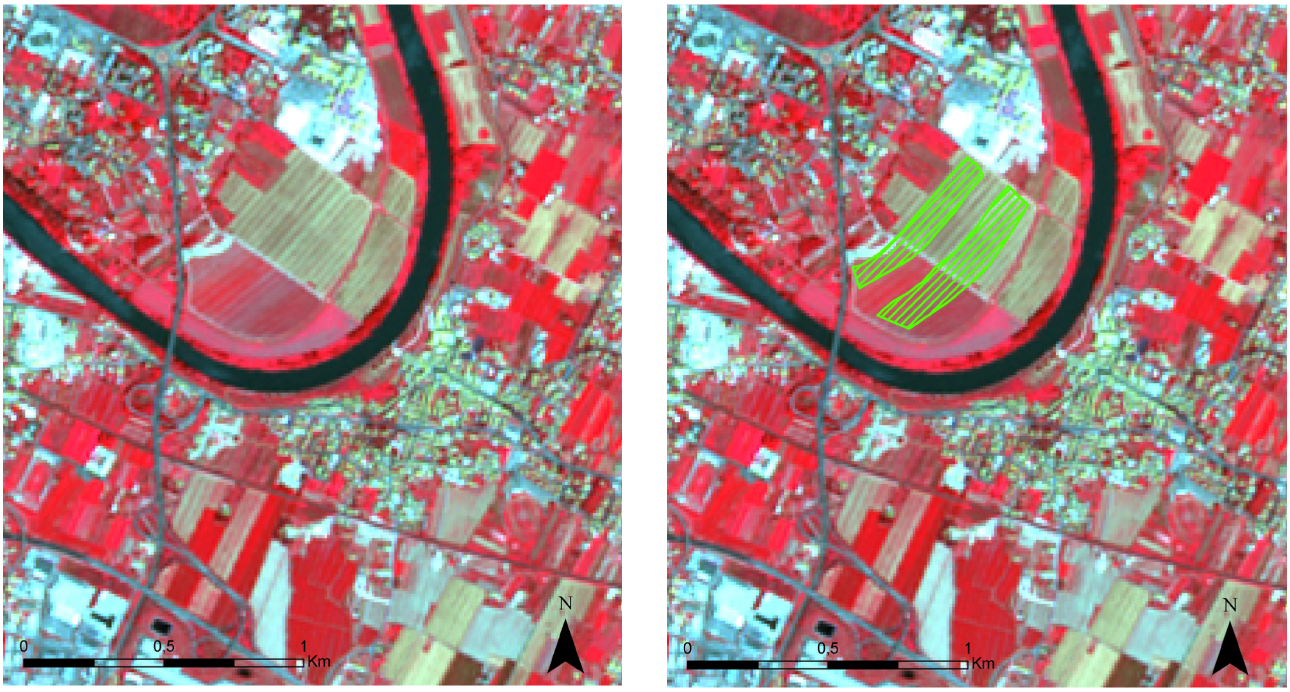

Figure 14. ALOS AVNIR-2 colour composite 432 RGB: south east area of Pisa. As in the SPOT 321 RGB composite, vegetation appears in different shades of red depending on the type and condition of vegetation due to its higher reflectance with respect to other surfaces in the near infrared range. Bare soils, roads and buildings may appear in various shades of blue, yellow or grey, depending on their composition. In this composite, the different vegetation growth, which is visible in the agricultural fields along the River Arno bend, could be related to an ancient Arno meander. The figure on the right shows the same composite with the traces overimposed.

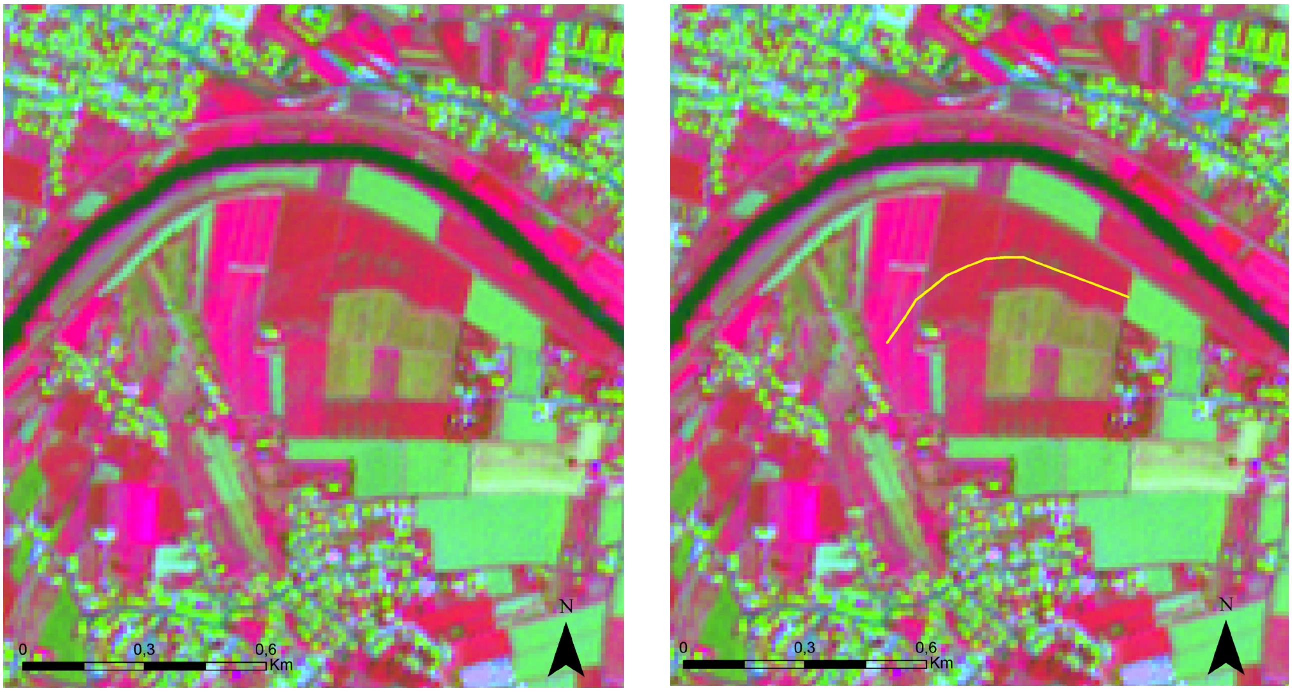

Figure 15. ALOS AVNIR-2 decorrelation stretching of 432 colour composite: River Serchio. This kind of transformation image removes the high correlation commonly found in multispectral datasets in order to produce a more colourful composite image (Gillespie *et alii,* 1986). The strong colours improve visual interpretation and make feature discrimination easier. In this case, a similar anomalous trace was detected across neighbour crops with different phases of vegetation growth.

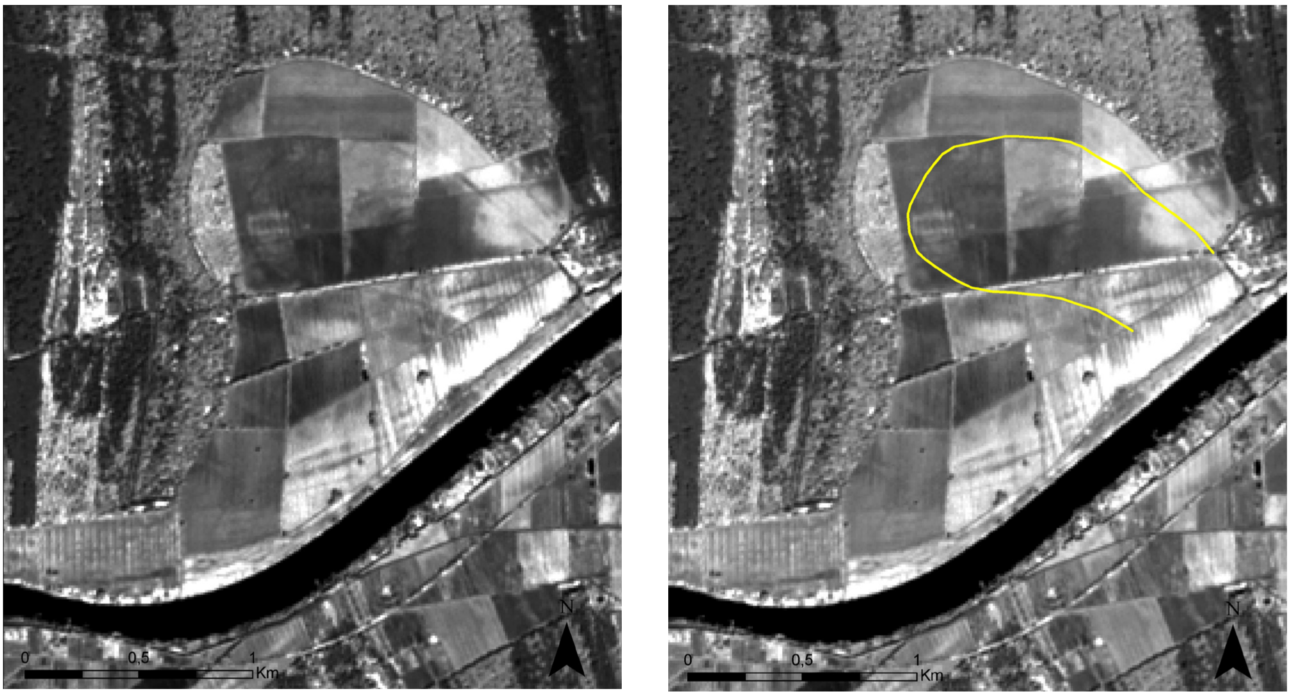

Figure 16. ALOS AVNIR-2 NIR band enhanced on the right side of the River Arno delta (San Rossore park, Cascine Nuove). A thin line that is darker than the surroundings is visible on the ALOS near infrared band, which could probably be related to an ancient Arno meander. The trace has been highlighted with a yellow line in the figure on the right.

Figure 17. ALOS AVNIR-2 123 PCA colour composite. This image is the result of the composite of the first three principal components carried out using the AVNIR-2 dataset. The decorrelation process enhanced the difference between band spectral information and the visual result is much more readable than traditional colour composites. The area represents the southern part of Massaciuccoli lake and image transformation confirmed evidence (yellow lines) of palaeochannels along the coastal pinewood already provided with SPOT analysis.

ALOS coverage due to the TERRA satellite orbit and this entailed that the whole study area could not be compared.

During the analysis and photointerpretation phase, more evidence was detected on the May ASTER acquisition due to the higher wetness content in the soils. Figure 18 shows the NDVI index calculated from the May ASTER scene. The NDVI or Normalised Differential Vegetation Index (Rouse *et alii*, 1974) is the most known and commonly used vegetation index in remote sensing applications. NDVI is calculated from the visible and near-infrared light reflected by vegetation and gives a measure of the amount and vigour of vegetation on the land surface (Tucker, 1979). Many factors affect NDVI values such as plant photosynthetic activity, total plant cover, biomass, plant and soil moisture, and plant stress. Thus, it was important for us to evaluate any anomalies in NDVI values (Fig. 18).

3. Results

The satellite images analysis led to validate many of the palaeotraces identified by means of photointerpretation and the main wetlands inferred by means of morphometric analysis for the study area. SPOT SWIR band information proved to be the most suitable for our purpose because of its relationship with the water content in vegetation and soils. The morphologic features derived from this analysis can be visualized in the MAPPA Web-GIS (http://mappaproject.arch.unipi.it) .

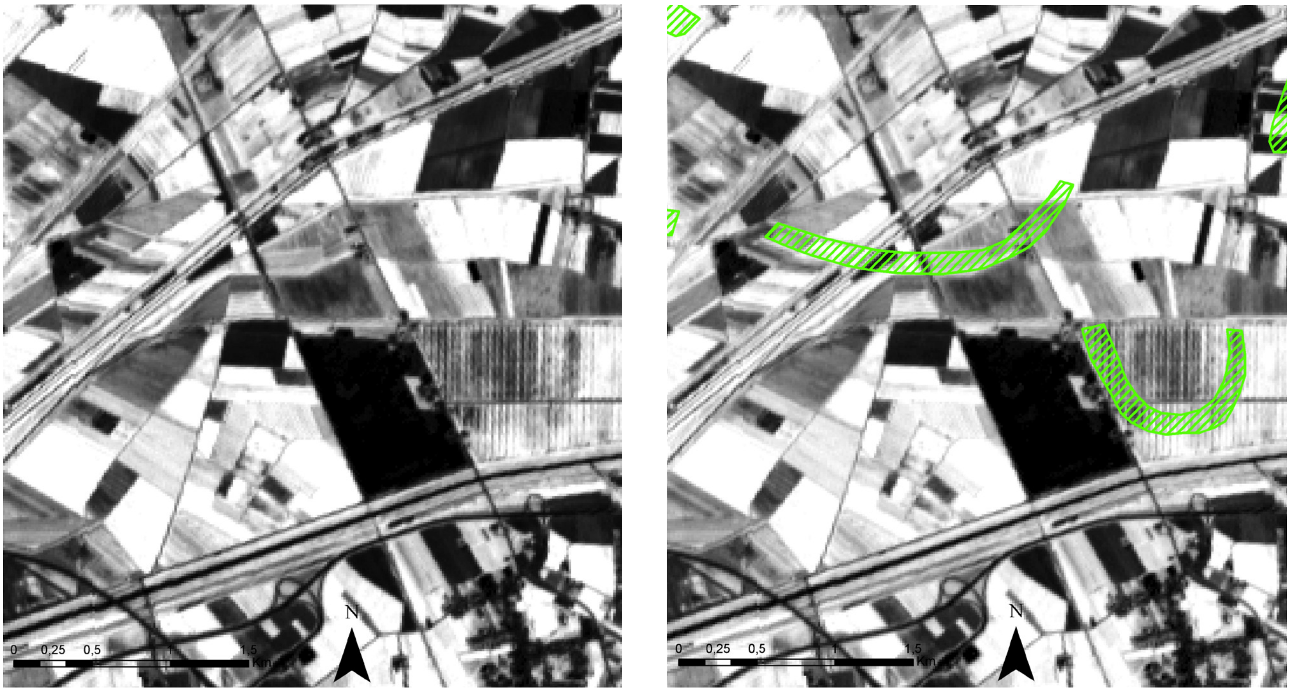

Figure 18. NDVI calculated on ASTER acquisition in May 2005. The vegetation index provides evidence of different vegetation conditions in the agricultural crops.

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